Active Noise and Occlusion Effect Cancellation in Headphones and Hearing Aids

Von der Fakultät für Elektrotechnik und Informationstechnik
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Aachen, June 2020 *Stefan Liebich*

Abstract

The perception of one's own voice is distorted when telephoning with headsets, or wearing hearing aids. The reason for this is the so-called *occlusion effect*, which occurs when ear canals are completely or partially closed by the headset or hearing aid. The occlusion causes amplification at low frequencies, and attenuation at high frequencies of one's own voice. The unnatural perception of one's own voice and of noise caused by chewing and swallowing are among the most common complaints of users. Furthermore, environmental noise might impair perception. In this thesis, both the unnatural perception of one's own voice and the disturbance by environmental noise are tackled by a novel signal processing approach.

The proposed solution solves the problem of the occlusion effect by actively emitting a compensation signal through the integrated loudspeaker. The approach is called *Occlusion Effect Cancellation* (OEC) and significantly improves the perception of one's own voice and of the acoustic environment. This novel approach combines methods of active noise cancellation (ANC, Noise Cancelling Headphone) with a personalized design. The bilateral headset contains two additional microphones per side, one inner and one outer, to acquire signals for the calculation of the compensation signals. A correctly balanced processing of the two microphone signals results in a "digital ear opening" and a much more natural perception of both one's own voice and of the environment. The extent of the digital ear opening is controllable. The system can also be operated as a noise cancelling headphone by changing the parameters to a conventional design to create an acoustic isolation from the environment.

This thesis proposes a novel robust approach based on digital filtering to solve the described problems. A combination of feedback and feedforward filter design allows for either approaching personal silence or a natural perception of one's own voice and the acoustic environment.

The main contributions are:

- Novel design concept for ANC / OEC systems which are robust w.r.t. acoustical variations of ear canals and earpiece fittings
- Novel structure for combined feedforward-feedback filters with adaptive stability control
- Analysis of variability of acoustic front-end (headset) as well as electronic back-end (digital signal processing incl. AD/DA-conversion) and implications

on ANC/OEC performance

- Real-time implementation of algorithms on a PC-sized dSPACE system as well as a mobile integrated circuit (Analog Devices ADAU 1777)
- Objective instrumental and subjective auditive evaluation of the concepts

The achieved ANC performance is comparable to that of a commercial reference system. The novel OEC algorithm revealed in both objective measurements and subjective listening tests, significant improvements of the own-voice perception.

To conclude, this thesis provides an in-depth discussion of the underlying problems of active noise and occlusion effect cancellation, design methods for digital control filters, an analysis of the implementation requirements for a real-time system as well as an evaluation based on both measurements and listening tests.

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